



## AIRCRAFT LIFT CONTROL SYSTEM

1 The present application is a continuation and claims priority of pending  
2 provisional patent application Serial No. 60/415,206, filed on October 1, 2002, entitled  
3 "Aircraft Lift Control System".  
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### 5 BACKGROUND OF THE INVENTION

#### 6 1. Field of the Invention

7 This invention relates generally to an aircraft lift control system and, more  
8 particularly, the invention relates to an aircraft lift control system having cooperative,  
9 high frequency, and dynamic-resonant aero-effectors.  
10

#### 11 2. Description of the Prior Art

12 Conventional active vibration control and flutter suppression systems are servo-  
13 hydraulic. Conventional servo-hydraulic technology is burdened by a set of undesirable  
14 characteristics which effectively restrict their use to large aircraft. The servo-hydraulic  
15 based systems have multiple critical parts are therefore susceptible to multiple point  
16 failures. The hydraulic servo valves, pumps, and pipe networks are very heavy. The  
17 compressibility of the hydraulic fluid, viscous losses in the moving hydraulic fluid and  
18 bandwidth limitations in the servo valves themselves limit these systems to relatively low  
19 frequency applications.

20 Accordingly, there exists a need for a high frequency bandwidth lift control for  
21 aircraft and other vehicles. In fact, a high frequency bandwidth lift control is of great  
22 practical importance for many civilian and military vehicles. For example, aircraft with  
23 stores, Uninhabited Air Vehicles (UAVs), and cruise missiles are all adversely affected  
24 by a lift driven divergent vibration response called flutter. Although lift control systems  
25 presently exist (e.g., servo-hydraulic systems and active structural components), these  
26 systems all have some limitations. The ideal lift control system, as disclosed by the  
27 present invention, would be small, lightweight, have fast response, consume little energy,  
28 and be transparent when not in use. Without such systems as described herein, some

1 vehicles prone to flutter, such as high-altitude, long-endurance UAVs are seriously  
2 limited in their capabilities.

#### 3 4 SUMMARY

5 The present invention is an aircraft lift control system mounted on an aircraft.  
6 The aircraft has at least one wing. The aircraft lift control system comprises an  
7 oscillating aero surface mounted to the aircraft wing. A resonant frame is connected to  
8 the oscillating aero surface. An actuator is mounted to the resonant frame wherein the  
9 sinusoidal force produced by the actuator on the resonant frame results in a resonant  
10 deformation in the resonant frame and resonant-sinusoidal displacement of the aero-  
11 surface.

12 The present invention further includes a method for controlling aircraft lift. The  
13 aircraft has at least one wing. The method comprising mounting an oscillating  
14 aero surface to the aircraft wing, connecting a resonant frame to the oscillating aero  
15 surface, mounting an actuator to the resonant frame, and producing a sinusoidal force on  
16 the resonant frame resulting in a resonant deformation in the resonant frame and resonant-  
17 sinusoidal displacement of the aero-surface.

#### 18 19 BRIEF DESCRIPTION OF THE DRAWINGS

20 FIG. 1 a is a perspective view illustrating a high frequency, dynamic-resonant  
21 aero-effector where motive force from the voice coil actuator is applied parallel to the  
22 motion of the aero-surface, constructed in accordance with the present invention;

23 FIG. 2 is a perspective view illustrating a high frequency, dynamic-resonant aero-  
24 effector where motive force from the voice coil actuator is applied transverse to the  
25 motion of the aero-surface, constructed in accordance with the present invention;

26 FIG. 3 is a photograph showing the high frequency, dynamic-resonant aero-  
27 effector of FIG. 2;

1        FIG. 4 is a perspective view illustrating the high frequency, dynamic-resonant  
2        aero-effector, constructed in accordance with the present invention, mounted in an aircraft  
3        wing; and

4        FIG. 5 is a perspective view illustrating the high bandwidth lift control system,  
5        constructed in accordance with the present invention, with two cooperative high  
6        frequency dynamic-resonant aero-effectors mounted in a short section of a wing.

#### 7 8        DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

9        As illustrated in FIGS. 1, 2, and 3, the present invention is an active lift control  
10       system, indicated generally at 10. The technology of the active lift control system 10 of  
11       the present invention is based on a set of cooperative high-frequency dynamic-resonant  
12       aero-effectors 12. The dynamic-resonant aero-effectors 12 work together to dynamically  
13       modify the pressure distribution over an aero-surface 14 to rapidly change the time  
14       average lift and moment coefficients of the aero-surface 14. The high frequency  
15       bandwidth of actuators 16 allow the actuators 16 to control rapid fluid-structure  
16       interactions such as flutter and to impose very rapid maneuvering loads on an airframe  
17       without causing structural overloads. The active lift control system 10 of the present  
18       invention will, therefore, result in higher safety margins and/or lower structural weights,  
19       thereby increasing aircraft payload and/or operational limits (range, altitude, etc.).

20       FIG. 1 illustrates the active lift control system 10 of the present invention includes  
21       the high frequency, dynamic-resonant aero-effector 12. The dynamic-resonant aero-  
22       effector 12 is composed of three main components: an actuator 16, a resonant frame 18,  
23       and an oscillating aero surface 20. In an embodiment of the present invention, the  
24       actuator 16 is a linear voice coil actuator. It should be note, however, that while the  
25       active lift control system 10 of the present invention has been described as using a linear  
26       voice coil actuator, using any type of linear or rotary actuator of electromagnetic or  
27       piezoelectric origin is within the scope of the present invention. Furthermore, preferably,  
28       the oscillating aero-surface 20 has a width of approximately two (2") inches and a length  
29       of approximately one (1") inch, operating at a frequency of approximately 1890 Hz.

1 While the present invention operates at approximately 72 Hz, it should be noted,  
2 however, that the oscillating aero-surface 20 can have a width of greater than or less than  
3 approximately two (2") inches, a length greater than or less than approximately one (1")  
4 inch, and operate at a frequency of greater than or less than approximately 1890 Hz. The  
5 small sinusoidal force developed by the voice coil effector on the middle mass results in a  
6 resonant deformation in the device columns and large resonant-sinusoidal displacement  
7 of the aero-surface 14.

8 FIG. 2 illustrates a high frequency, dynamic-resonant aero-effector 12 design  
9 where the motive force from the voice coil actuator is applied transverse to the motion of  
10 the aero-surface 14. In this embodiment, the small sinusoidal force developed by the  
11 voice coil effector on the middle mass results in a resonant rocking motion of the central  
12 mass, large resonant deformation of the device columns, and consequently large resonant-  
13 sinusoidal displacement of the aero-surface 14.

14 FIG. 3 illustrates the transverse high frequency, dynamic-resonant aero-effector 12  
15 of the present invention. The five small cylindrical features are pressure taps mounted in  
16 a cover for use in the wind tunnel.

17 FIG. 4 illustrates the high frequency, dynamic-resonant aero-effector 12 installed  
18 in an aircraft wing. The top of the oscillating aero-surface 20 fits flush with the upper  
19 surface of the wing when the actuator 16 is unpowered. An acoustic frequency  
20 alternating current is transmitted through the voice coil device to produce a force which  
21 varies sinusoidally in time. The frequency of the voice coil alternating current is  
22 preferably selected to match the elastic resonance frequency of the resonant frame and  
23 oscillating aero-surface mass-spring system. This results in large amplitude oscillatory  
24 motion of the aero-surface 14 perpendicular to the wing surface. The top portion of  
25 oscillating aero-surface 20, therefore, cyclically projects into the air flowing over the top  
26 surface of the wing. The projected aero-surface 20 disturbs the smooth flow over the  
27 wing, causing local flow separation and vortex structures. These flow structures reduce  
28 the vacuum pressure at local points on the wing resulting in a change in the coefficient of  
29 lift which can be used to maneuver the aircraft or to suppress aerodynamic flutter.

1 Switching off power to the device returns the top of the oscillating aero-surface 20 to a  
2 position flush with the upper wing surface.

3 Practical lift control systems of the present invention are composed of two or  
4 more aero-effectors operated cooperatively. FIG. 5 illustrates an example high bandwidth  
5 lift control system 10 composed of two cooperative high frequency dynamic-resonant  
6 aero-effectors 12 mounted in a section of a wing. The individual operation of each device  
7 12 is the same as previously described, however, the specific displacement, phase  
8 relationship, and operation frequency of the second device is selected to amplify the lift  
9 modification effects of the first device 12. A large number of small-scale devices 12  
10 could be combined in this manner. A wave-like flow disturbance structure originates at  
11 the first device 12 and then very rapidly grows as subsequent effectors 12 cause flow  
12 disturbance resonance. The attenuation of the lift effects would follow a similar spatial-  
13 time pattern. The cyclic displacement of each of the aero-effector devices 12 would be  
14 actively canceled resulting in a return to smooth flow over the wing.

15 The present invention leads to structural weight reductions on high performance  
16 unmanned air vehicles, as flutter divergence would be actively controlled. Presently,  
17 these aircraft must be over-built to protect against flutter which results in a significant  
18 weight increase. The present invention could also be used for cruise missiles and  
19 possibly high performance, light civilian jet aircraft. Since divergent flutter vibration  
20 often leads to the destruction of an aircraft, the present invention suppresses the divergent  
21 flutter vibration with minimal system weight and power demands.

22 The foregoing exemplary descriptions and the illustrative preferred embodiments  
23 of the present invention have been explained in the drawings and described in detail, with  
24 varying modifications and alternative embodiments being taught. While the invention  
25 has been so shown, described and illustrated, it should be understood by those skilled in  
26 the art that equivalent changes in form and detail may be made therein without departing  
27 from the true spirit and scope of the invention, and that the scope of the present invention  
28 is to be limited only to the claims except as precluded by the prior art. Moreover, the

- 1 invention as disclosed herein, may be suitably practiced in the absence of the specific
- 2 elements which are disclosed herein.
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